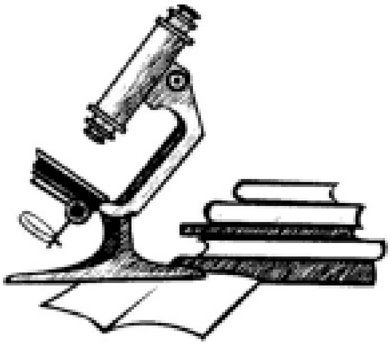

Research, reviews & patents

Many compounds-related patents are continually issued from the US Patent Office. This section overviews some of the recent ones; for this article the main focus is on wide bandgap semiconductors and devices therefrom. Patents from the first two months of the year come from various US, Japanese and Korean companies revealing something of what is going on behind the scenes in the leading R&D laboratories around the world.

In US patent #6,998,690 is described a GaN-based device from the days when Shuji Nakamura was still with Nichia Industries. The patent is dated February 14, 2006, but originates from several years ago of course. The device consists of a III-nitride layer over a substrate with an ohmic electrode provided on top formed of a metallic material, and has been annealed.

Cree Inc is also a regular poster of new patents in the wide bandgap compounds. Recent awards include US Patent #6,995,398 for DA McClure, et al., involving methods of treating a SiC substrate for improved epitaxial deposition and resulting structures and devices. The treatment method includes the steps of implanting dopant atoms of a first conductivity type into the surface of a conductive SiC wafer having the same conductivity type as the implanting ions at one or more predetermined dopant concentrations. Following the implant the wafer is annealed and then an epilayer is grown thereon.

Conductive buffers were then formed on the implanted substrates. The interfacial voltage (i.e., the voltage drop attributable to the substrate/buffer interface) was measured at three locations on the wafer and an average value was calculated. The average values are plotted against the 25 keV implant dose. As shown in Figure 1, the interfacial voltage of the substrate/buffer interface decreases with increasing dosage.

In contrast to sapphire favoured by Nichia and others, SiC can be conductively doped, and therefore can be effectively used to manufacture a vertical group III-nitride LED. In addition, SiC has a relatively small lattice mismatch with GaN, which means that high-quality group III-nitride material can be grown on it. SiC also has a high coefficient of thermal conductivity, which is important for heat dissipation in high-current devices such as laser diodes.

Despite the advance of Cree's so-called '606' patent, there remains a measurable voltage drop at the interface between a conventional SiC substrate and the conductive buffer layer. It is desirable to reduce this voltage drop in order to reduce the overall Vf of the resulting device. This invention comprises a SiC wafer with first and second surfaces of predetermined conductivity type. A region of implanted dopant atoms extends from the first surface into the SiC wafer, the region having a higher concentration than the initial carrier concentration in the remainder of the wafer. A conductive buffer region is on the first surface of the conductive SiC wafer, an active region is on the conductive buffer region, a first ohmic contact is on the active region, and a second ohmic contact is on the second surface of the wafer.

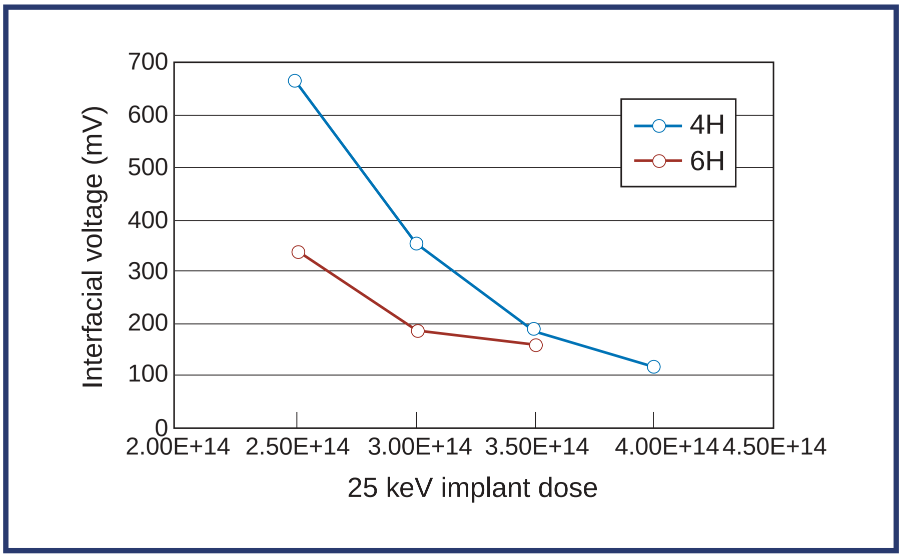

Figure 1: The interfacial voltage of the substrate/buffer interface decreases with increasing dosage.

Cree continues to tackle and refine the technology for improved performance materials and devices. In another US patent (#6,995,032) MT Bruhns, et al., describe a trench cut process for LEDs. A method is provided for forming semiconductor devices using a semiconductor substrate having first and second opposed sides, and at least one device layer on the second side of the substrate, the at least one device layer including first and second device portions. A first trench is formed in the first side of the substrate between the first and second device portions. A second trench is formed in the second side of the substrate between the first and second device portions.

The US Patent #6,987,281 by JA Edmond, et al., also of Cree, entitled '*Group III nitride contact structures for light emitting devices*' a superlattice contact structure for light emitting devices includes a plurality of contiguous p-type Group III nitride layers. The contact structure may be formed of p-type InN, AlInN, or InGaN. Also shown is a light emitting device that incorporates the disclosed contact structures.

Quantum well emitters

Another US company which is very active in patenting wide bandgap opto technology is Lumileds Lighting. For instance, in US patent #6,995,389, JC Kim, et al., have prepared heterostructures for III-nitride light emitting devices.

Heterostructure designs are disclosed that may increase the number of charge carriers available in the quantum well layers of the active region of III-nitride light emitting devices such as light emitting diodes. In a first embodiment, a reservoir layer is included with a barrier layer and quantum well layer in the active region of a light emitting device. In some embodiments, the reservoir layer is thicker than the barrier layer and quantum well layer, and has a greater indium composition than the barrier layer and a smaller indium composition than the quantum well layer. In some embodiments, the reservoir layer is graded. In a second variant, the active region of a light emitting device is a superlattice of alternating quantum well layers and barrier layers. In some embodiments, the barrier layers are thin such that charge carriers can tunnel between quantum well layers through a barrier layer.

In a related US Patent #6,989,555, Goetz, et al., describe strain-controlled III-nitride light emitting devices. In a III-nitride light emitting device, a ternary or quaternary light emitting layer is configured to control the degree of phase separation. In some embodiments, the difference between the InN composition at any point in the light emitting layer and the average InN composition in the light emitting layer is less than 20%. In some embodiments, control of phase separation is accomplished by controlling the ratio of the lattice constant in a relaxed, free standing layer having the same composition as the light emitting layer to the lattice constant in a base region. For example, the ratio may be between about 1 and about 1.01.

Kopin improves bonding pad

In US Patent #7,002,180, by S T-H Oh, et al., of Kopin Corp, a 'bonding pad for gallium nitride-based light-emitting device,' is described.

A bonding pad for an electrode is in contact with p-type gallium nitride-based semiconductor material that includes aluminium. The bonding pad may also include one or more metals selected from the group consisting of palladium, platinum, nickel and gold. The bonding pad can be used to attach a bonding wire to the p-electrode in a semiconductor device, such as a light-emitting diode or a laser diode without causing degradation of the light-transmission and ohmic properties of the electrode. The bonding pad may be formed of substantially the same material as an electrode in making an ohmic contact with n-type gallium nitride-based semiconductor material (n-electrode). This allows the bonding pad and the n-electrode to be formed simultaneously when manufacturing a GaN-based light-emitting device which substantially reduces the cost to manufacture the device.

Since p-type GaN-based semiconductor layers have only moderate conductivity, a p-electrode typically is formed to cover substantially the entire surface of the p-type GaN-based semiconductor layer in a GaN-based LED in order to ensure uniform application of current to the entire layer and obtain uniform light emission from the light-emitting device. However, this geometry requires that the p-electrode be light-transmissive so that light emitted by the light-emitting device can be observed through the p-electrode. Typically, the p-electrode layer must be very thin in order to be light transmissive and thus, it is difficult to attach a bonding wire directly to it. Therefore, a bonding pad is used to attach the bonding wire to the p-electrode. However, metallic materials used in the bonding pad can migrate into the p-electrode causing degradation of the light-transmission and ohmic property of the electrode. In the past, this problem has been particularly encountered when the bonding pad includes aluminium.

Bonding pads formed by the method of the invention adhere satisfactorily to the bonding wire and do not degrade the light transmission or ohmic property of the p-electrode. In addition, the metallic materials used to form the bonding pads of the invention can also be used to form an electrode that forms a good ohmic contact with an n-type gallium nitride-based semiconductor layer. Thus, when manufacturing GaN-based devices, the bonding pad for the p-electrode can be formed simultaneously with the n-electrode, substantially reducing the cost to manufacture of the device.

It is preferable to anneal the n-electrode by heating the n-electrode to a temperature in the range of between about 350 and 550°C for about 30 s to 1 h. A preferred annealing temperature range is between about 400 and 500°C. The bonding pad and the n-electrode are preferably annealed simultaneously.

For the full patents visit the US Patent and Trademark Office website: www.uspto.gov

Sony patents novel pyramidal LED

In US Patent #7,002,182, by H Okuyama, et al., of Sony, a 'semiconductor light emitting device integral type semiconductor light emitting unit image display unit and illuminating unit' is described.

The fabrication sequence involves an underlying n-type GaN layer grown on a sapphire substrate via a growth mask made from silica film (or alumina, tungsten film, etc.). An n-type GaN layer having a hexagonal pyramid shape, is selectively grown on a part, exposed from an opening of the growth mask of the underlying n-type GaN layer. Afterwards, the mask is removed by etching and then an active layer and a p-type GaN layer are sequentially grown on the entire substrate so as to cover the hexagonal pyramid shaped n-type GaN layer hence to form a light emitting device. An n-side electrode and a p-side electrode complete the structure.

In the photolithography step required for forming the opening of the growth mask, a resist is brought into close-contact with a mask plane, followed by partial removal of the resist. In this removal of the resist, the resist is liable to remain in micro-gaps of the growth mask. This is hard to removed. As a result, at the subsequent growth at a high temperature, the remaining resist acts as an impurity source, tending to degrade characteristics of the GaN layers, particularly, the p-type GaN layer.

The group said that the luminous efficiency is enhanced by setting the size of the p-side electrode, 20, in a range of about 50% or less of the size of the hexagonal pyramid shaped GaN layer. This is due to pits present on the lower side of the hexagonal pyramid shaped p-type GaN layer and abnormal growth portions formed in the vicinity of the pits. If the p-side electrode is formed on these, the contact characteristic of the electrode is degraded, lowering luminous efficiency. Since the size of the p-side electrode is set in a range of about 50% or less of the size of the hexagonal pyramid shaped p-side GaN layer, the p-side electrode can be formed in such a manner as not to be overlapped to the abnormal growth portions.